

24-Hour Traffic-Responsive Ramp Metering

Requested by

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The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

Executive Summary

Background

Caltrans is interested in deployments of always-available ramp metering—systems that gauge traffic on a 24-hour basis and activate when mainline congestion warrants their operation. While intelligent transportation systems (ITS) technology to enable ramp meters in this manner is well established, it is important for Caltrans to learn from the experiences of transportation agencies in the United States and worldwide that may already be operating traffic-responsive ramp meters on a 24-hour basis.

This Preliminary Investigation sought to identify deployments of 24-hour ramp metering and document possible impacts, obstacles to implementation, and legal and signings/signaling issues, along with available information on related public outreach, perception and acceptance. We also sought research and guidance documents that specifically address 24-hour traffic-responsive ramp metering.

Summary of Findings

This Preliminary Investigation includes findings in the following areas.

- National Resources
- Deployment in the United States
- International Resources and Deployment

National Resources

- Two FHWA publications directly address the central topics of this Preliminary Investigation:
 - Section 8.3.1—Ramp Metering Operations of the 2006 *FHWA Ramp Management and Control Handbook* discusses at length considerations for ramp metering hours of operation.
 - Chapter 4I. Traffic Control Signals for Freeway Entrance Ramps of FHWA's 2009 *Manual on Uniform Traffic Control Devices* provides standards for design and operation

of ramp control signals. The only formal request for clarification on this chapter was one previously submitted by Caltrans.

- RITA's website on ITS deployment statistics presents the findings of the 2010 survey of 1,600 transportation agencies, which addresses deployment of ramp metering and use of metering to meet different traffic management strategies.
- We corresponded with or interviewed four individuals from FHWA: one from the national Office of Operations and three from state Division Offices (California, Minnesota, and Washington State). They provided information and speculation on where 24-hour ramp metering might be used in the United States.

Deployment in the United States

In coordination with Caltrans, we conducted informal email surveys of memberships of two national groups consisting of state DOT members: the AASHTO Highway Subcommittee on Systems Operations and Management and the Transportation Management Center (TMC) Pooled-Fund Study. The information in this section incorporates the results of these surveys.

- *California*

A representative from FHWA's California Division provided an external perspective on 24-hour ramp metering in California. We also cited key Caltrans publications related to ramp metering: Caltrans' 2011 *Ramp Meter Development Plan* and 2000 *Ramp Meter Design Manual*.

- *Agencies with 24-Hour Ramp Metering*

We learned about and corresponded with five DOTs that reported using 24-hour ramp metering: Illinois DOT, Kansas City Scout (co-managed by Missouri and Kansas DOTs), Minnesota DOT, Texas DOT, and Washington State DOT. It was not clear from our research whether Virginia DOT uses 24-hour ramp metering.

The following summary items and common themes emerged during our investigation:

- There has not been a negative **public reaction**.
 - Illinois reported no negative public reaction to traffic-responsive 24-hour ramp metering, since drivers would be "sitting on the ramp anyway."
 - Kansas City Scout conducted an outreach campaign to build expectation among Scout's customers "that it would be utilized whenever ramp metering is warranted."
 - Texas has had "no negative complaints. In fact complaints have gone down because the meters do not come on when the traffic is light and not warranted."
- States addressed when traffic-adaptive 24-hour metering **activates and operates**.
 - In Illinois, "the metering would activate on weekends in a congested stretch, and would shut down when free flow returned."
 - In Kansas City, "traditionally it activates in the peak hours and during major incidents."
 - In Minnesota, "it's pretty rare that we turn meters on outside of the normal hours for incident related congestion. The meters would have to manually activated during these situations and we would probably only get limited benefits of the meters under these conditions."
- Minnesota also addressed **work zones**: "Most work zones we lose ramp metering because we lose detection and communication for the meter. We've had a couple projects where the roadway was reduced from two lanes to one where we did metering. It was only marginally effective since the mainline capacity was so greatly reduced."

- Texas is **expanding use** of 24-hour ramp metering: “Houston has 80 percent of its ramp meters operating 24/7. Texas DOT is working on converting 100 percent of the meters to traffic responsive and should have that completed by the end of the summer.”
- Washington State also discussed:
 - **Exceptions** to 24-hour metering: “The exception is set per specific meter to handle local abnormality, such as on-ramps adjacent to sport stadium where there is tremendous need to flush traffic off the surface street network. We have tagged these ramps as ‘not to be turned on (automatically) between 9:00 p.m. and 5:00 a.m.’ ”
 - **System software, parameters and adjustments:** “Our software ... was designed with the 24/7 operation in mind. The software continues to calculate and log metering rate every 20 seconds even when the meter is not “on.” ... The idea is to tune the automatic on/off parameters so that the meter would not be turned on at really odd time such as late night during the most unexpected hours and low volumes.”
 - **Signaling.** “Regarding MUTCD, I do not think they dictate the ‘window of operation,’ but rather the display layout, the termination of ‘phase.’ However, I still believe the MUTCD went overboard suggesting the meter signal be the same as intersection signal in all aspects.

We also cited relevant state resources: a research study in Minnesota, research-based ramp metering guidelines for Texas, and a Washington State web site.

- *Other Agencies with Ramp Metering*

We learned about seven DOTs that do not appear to use 24-hour ramp metering: Arizona DOT, Colorado DOT, Georgia DOT, Regional Transportation Commission of Southern Nevada, New York State DOT, North Carolina DOT and Wisconsin DOT. Perspectives from the people we corresponded with may prove of use to Caltrans, such as these summary points:

- Some agencies said that **24-hour ramp metering would be feasible**, including Arizona, Colorado and New York State.
- Several agencies described the **operation modes of their ramp meters**, including the basis for determining when to set the fixed time of day of operation. Wisconsin described both fixed-time ramp meters and traffic-responsive ramp meters that run on a 24-hour basis.
- The following **challenges and concerns** about 24-hour ramp metering were raised:
 - Colorado detailed functionality issues and described how a “construction work zone continues to be a problem as queues build and are then released.”
 - Georgia listed three specific concerns: “1. Drivers don’t expect the meters to be on at 2:00 am for example. 2. Most of the congestion we might experience in those odd-ball hours would probably be related to an incident, in which case metering has limited benefit in my opinion. 3. Detection system failures could lead to meters running in strange hours and would cause the public to question their operation.”

International Resources and Deployment

- *Guidance Documents*

We cited two documents that provide international guidance on ramp metering:

- *Freeway Ramp Signals Handbook* from VicRoads in Victoria, Australia, which provides detailed operational guidance.

- *Ramp Metering Deployment Guideline*, a publication of EasyWay (a “trans-European project co-financed by the European Commission”) aimed at harmonizing ramp metering throughout Europe.
- *Deployment*
We discussed deployment of ramp metering in five nations: Australia, France, the Netherlands, Germany, and Sweden.
 - Among these, we were only able to receive confirmation that 24-hour ramp metering is used in the Netherlands per a representative of the National Traffic Management Centre.
 - It was suggested, though not confirmed, that 24-hour ramp metering is also in use or in the process of implementation in Australia and France.

Gaps in Findings

Documentation about a given agency’s ramp metering system commonly does not include details on hours of operation. This is true whether a system is documented by the agency itself or as part of a research study. Therefore, it was necessary to rely on feedback from practitioners to learn about always-available 24-hour ramp metering. As a result, we were largely limited to information received from individuals we could reach during the period of time allotted for this Preliminary Investigation. It is to be expected there are more instances of 24-hour ramp metering beyond those documented in this Preliminary Investigation.

Another challenge associated with this effort was the pace with which information about ramp metering implementation becomes outdated. This is caused both by the deployment of some installations and the removal of others. This is evidenced in our discussion of Minnesota’s 2000 *Twin Cities Ramp Meter Evaluation* presented in the “Agencies with 24-Hour Ramp Metering” section of this Preliminary Investigation.

We did not find a great deal of information about legal issues or signing/signaling concerns. It was noteworthy that Caltrans appears to have been the only state to seek official clarification from FHWA on ramp metering signaling in the MUTCD.

Next Steps

Most of the individuals we corresponded with expressed that they would be open to discuss this topic in greater details with Caltrans. A continuation of the dialogue started through this Preliminary Investigation could help provide detailed answers to Caltrans’ specific questions.

A few avenues for additional information could be pursued further if they are of interest to Caltrans:

- It was not clear from our investigation whether the users of the Heuristic Ramp-Metering Coordination (HERO) system (Australia, France, Virginia) were operating it on a 24-hour basis. If this were confirmed, then perhaps more information could be sought from these users.
- As noted in the “U.S. DOT Guidance” section of this Preliminary Investigation, it was suggested that FHWA’s Minnesota office had conducted a synthesis on the subject of ramp metering. We were unable to get more information on this document, but it might be relevant to Caltrans’ questions on this topic.
- A more comprehensive survey with all participants in the RITA survey might help identify more users of 24-hour ramp metering for further inquiry. Though agencies are named publicly in the survey, individual respondents’ names and emails are not, so coordination with RITA would be necessary for such a task.

Contacts

During the course of this Preliminary Investigation, we spoke to or corresponded with the individuals listed below. Summaries of our communication appear throughout this investigation in the appropriate section of the report.

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National Resources

We reviewed national guidance documents and reached out to individuals to inquire about the extent of 24-hour ramp metering and the issues involved. Documentation from U.S. DOT and feedback from FHWA representatives appear in this section of the report.

U.S. DOT Guidance

FHWA Ramp Management and Control Handbook, 2006

http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/

FHWA provides comprehensive guidance on ramp metering planning and consideration in this handbook.

Section 8.3.1 Ramp Metering Operations

(http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/8_1.htm#831) discusses considerations for hours of operation and associated monitoring needs.

Hours of Operation

Most agencies operate ramp meters during peak periods only. In some systems that have congestion outside the peak commute hours, meters may be operational for longer periods, during mid-day, evenings, or on weekends. It is good practice for an agency to operate ramp meters only during peak commute hours when ramp metering is first implemented, in order to get staff experienced in operating metering, make the system predictable, and reduce motorist confusion or frustration. Operating at predictable times, especially when metering is first implemented, allows the public to know with relative certainty when ramp meters will be on and off.

As motorists and operators become more familiar with the operation of the system and if congestion occurs outside the peak commuting hours, metering times can be expanded. For instance the Washington State Department of Transportation (WSDOT) operated meters in the City of Seattle from about 6:00 to 8:30 a.m. and 3:30 to 6:30 p.m. on Monday through Friday when the system was first implemented. Over the years, the window for metering expanded in the morning and evening and now includes the weekends in some areas of the region.

In certain situations, such as when congestion occurs at unpredictable times, mature ramp metering systems (i.e., those that have been in operation for a significant amount of time) may be turned on at any time of the day on any day of the week when conditions warrant their use. Operating ramp meters in off-peak hours, however, is not recommended for relatively newer systems where residents are not familiar with ramp metering. It is important for residents to get used to driving through ramp meters before expanding the times of day that meters could operate.

Mature ramp meter systems may also be activated outside scheduled time frames when emergencies occur or in unique situations. In some systems, meters may be activated automatically during off-peak periods when traffic congestion occurs because of collisions or other incidents.

Practitioners responsible for operating ramp meters should be well trained and familiar with the ramp metering system. They also need to have a strong understanding of typical traffic patterns and problems. Operators should monitor real-time traffic conditions to determine when it is most beneficial to turn on or off particular ramp meter(s).

Ramp Meter Monitoring and Operation

As mentioned previously, most ramp meter systems are turned on at the same times every day. In others, operators monitor conditions and modify the times accordingly. In either case, it is important for operators or operations staff to monitor the operation of the system.

When meters are active, operators should periodically monitor each ramp meter to confirm that meters are functioning correctly and adjust operating parameters when appropriate. Closed-circuit television (CCTV) cameras located on the freeway or local arterial streets may be used to visually monitor metered ramps. If metering is not centrally controlled and if there are no cameras that allow operators to monitor the metered ramps, operations staff should schedule routine field visits to observe the metering operation to determine if adjustments are needed. Operator responsibilities like these need to be documented for quick reference when needed. The operator manual or handbook that documents responsibilities can also be used for training. Figure 8-1 provides an example of general operator responsibilities as they pertain to ramp meter operations. The handbook in which these responsibilities are outlined also provides more specific operational procedures that the operators can reference when needed. An example of more detailed operational procedures pertaining to ramp metering is provided in Figure 8-2.

Operational plans and procedures also need to be developed that dictate how ramp meters are to be controlled during incidents and major emergencies. For instance, if smoke from a brush fire has limited the flow of traffic in all lanes of a freeway, operators need to know if they should turn off meters, and when metering should resume.

Manual on Uniform Traffic Control Devices (MUTCD), Chapter 4I. Traffic Control Signals for Freeway Entrance Ramps, FHWA, 2009.

<http://mutcd.fhwa.dot.gov/hdm/2009/part4/part4i.htm>

This chapter of the MUTCD provides standards for design and operation of ramp control signals. Guidance on time of operation appears in Section 4I.03:

- 01 Operational strategies for ramp control signals, such as periods of operation, metering rates and algorithms, and queue management, should be determined by the operating agency prior to the installation of the ramp control signals and should be closely monitored and adjusted as needed thereafter.
- 02 When the ramp control signals are operated only during certain periods of the day, a RAMP METERED WHEN FLASHING (W3-8) sign (see Section 2C.37) should be installed in advance of the ramp control signal near the entrance to the ramp, or on the arterial on the approach to the ramp, to alert road users to the presence and operation of ramp meters.

Standard:

- 03 The RAMP METERED WHEN FLASHING sign shall be supplemented with a warning beacon (see Section 4L.03) that flashes when the ramp control signal is in operation.

FHWA's only published Interpretation Letter related to this section of the MUTCD is in response to a letter submitted by Caltrans' Zhongren Wang.

Excerpted from Interpretation Letter 2(09)-62 (I) — Use of Signal Ahead Signs for Ramp Metering
http://mutcd.fhwa.dot.gov/resources/interpretations/2_09_62.htm

Thank you for your e-mail message of October 29 requesting an official interpretation concerning the use of Signal Ahead (W3-3) signs for ramp metering operations. Your e-mail message references the 2006 Ramp Control Handbook which shows the Signal Ahead (W3-3) sign as part of the advanced warning for ramp metering.

When the 2006 Ramp Control Handbook was published, the 2003 Edition of the MUTCD was in effect. The 2003 MUTCD did not address ramp metering signing. It was not until the 2009 Edition of the MUTCD that ramp metering warning signs were incorporated into the Manual with the RAMP METER AHEAD (W3-7) sign and the RAMP METERED WHEN FLASHING (W3-8) sign. One of the primary concerns with the Signal Ahead (W3-3) sign is that the W3-3 sign warns of a traffic control signal, which assigns right of way to the vehicle. A ramp meter does not. The green indication on the ramp meter allows movement, but does not assign right of way. The driver still has to yield to traffic on the main line of the freeway or expressway. Additionally most ramp meters use a 2-section signal face (red and green only), which differs from the 3-section signal face illustrated on the Signal Ahead (W3-3) sign. Thus, the symbol on the W3-3 sign does not accurately represent the existing condition.

It is the FHWA's official interpretation that the use of a Signal Ahead (W3-3) sign in advance of a ramp meter would not be in substantial conformance with the MUTCD. Furthermore, the W3-7 and W3-8 signs are the appropriate signs to be used with ramp metering as described in Section 2C.37 of the 2009 Edition of the Manual on Uniform Traffic Control Devices.

We have numbered and titled this Official Interpretation as "2(09)-62 (I) — Use of Signal Ahead Signs for Ramp Metering." If you have further questions on this matter, please contact Mr. Eric Ferron of our MUTCD Team at 720-963-3206 or eric.ferron@dot.gov.

Intelligent Transportation Systems (ITS) Deployment Statistics, U.S. DOT Research and Innovative Technology Administration (RITA), 2010

<http://www.itsdeployment.its.dot.gov>

This site presents results of RITA's 2010 ITS Deployment Tracking Survey. The survey covered nearly 1600 transportation agencies in 108 cities.

- General statistics on ramp meter deployment may be of interest to Caltrans.
(<http://www.itsdeployment.its.dot.gov/FM.aspx> and click "Ramp Control" at left)
 - A total of 29 agencies reported having deployed ramp metering.
(http://www.itsdeployment.its.dot.gov/agencies.aspx?System=FM&Field1=HaveRampMeters_yes)
- The survey did not address 24-hour availability of ramp metering, but it did capture the following use categories:
 - “Circumstances under which an agency meters traffic on ramps as a traffic management strategy:”
 - Time of day (recurrent congestion) — 27 agencies
 - Traffic incidents — 15 agencies
 - Planned special events — 11 agencies
 - Weather (e.g., fog, rain, snow) — 3 agencies
 - Evacuation — 2 agencies

Lists of specific agencies responding to each question are linked on the web page above.

- The opinion portion of the survey showed that four agencies planned to deploy traffic adaptive signaling in the period of 2010-2013.
<http://www.itsdeployment.its.dot.gov/opinion.aspx> and click the "Arterial Management" tab

FHWA Correspondence and Interviews

We spoke to and corresponded with several FHWA staff members for further guidance on deployment of 24-hour ramp metering.

- **California.** Jesse Glazer, ITS & Operations Engineer for Southern California, said that he could not comment beyond ramp metering in Southern California. He guessed that “traffic-responsive is common but 24-hour operation is rare.” His detailed comments on California operations appear in the “Deployment in the United States” section of this Preliminary Investigation.
- **Minnesota.** James McCarthy, Statewide Planning Engineer for Minnesota, wrote that “I know Minnesota DOT operates ramp meters, variable speed limits and lane control 24/7. It is rare that system will activate off peak but it does respond to congestion and is not limited to peak periods.” It was suggested in the email thread that McCarthy had conducted a synthesis on the subject. Per Jim Hunt (below), this is not a published document.
- **Washington State.** James Colyar, Transportation Mobility Specialist for ITS for Washington, wrote: “Washington State DOT in the Seattle area just implemented an automated ramp metering on/off functionality that will enable metering activation 24/7. Their base algorithm is system-wide and responsive already.”

“Beyond that, Chicago, Seattle, Minneapolis, Portland, Kansas City, and Salt Lake City answered in our recent OEI survey that they have ramp meters operational on multiple facilities; control is responsive/actuated to system-wide conditions (i.e., optimizing flow along an entire facility or system wide); and the meters are integrated in a TMC. This doesn’t mean that they actuate their meters 24/7, but they are the most likely metro areas to do this.”

- **National.** Jim Hunt with FHWA Office of Operations said that his office oversees active traffic demand management systems, and dynamic ramp metering falls under that umbrella. He stated that ramp metering has high benefit-to-cost and might be underutilized. FHWA plans to talk to its division offices—locations that have ramp metering and those that don’t but could possibly benefit from it—to develop strategies for future research or guidance. Per Hunt, progressive cities for ramp metering include Atlanta and Minneapolis.
- In addition, Jameela Hayes, AASHTO liaison to the Subcommittee on Systems Operations and Management wrote, “A great resource for traffic-responsive ramp metering is Robert Rupert.”

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We were not able to reach Rupert for this Preliminary Investigation.

Deployment in the United States

The memberships of two national groups consisting of state DOT members were contacted for this Preliminary Investigation.

AASHTO Highway Subcommittee on Systems Operations and Management (SSOM)

<http://ssom.transportation.org/Pages/SSOMMembershipandOrganization.aspx>

This is the AASHTO committee concerned with ramp metering and other ITS.

Transportation Management Center (TMC) Pooled-Fund Study

<http://tmcdfs.ops.fhwa.dot.gov/>

Caltrans is a member of this pooled fund study that is addressing TMC-related issues of common concern among several states.

CTC & Associates conducted an informal email survey of the members of the AASHTO Highway Subcommittee on Systems Operations and Management. Concurrent with our work on this Preliminary Investigation, Caltrans' Zhongren Wang similarly conducted an informal email survey of the members of the Transportation Management Center (TMC) Pooled-Fund Study.

We have incorporated the survey results into this section of the report. The findings include an outside perspective on Caltrans' ramp meters, information on five domestic agencies with 24-hour traffic-responsive ramp metering, and input on eight domestic agencies that do not currently use 24-hour ramp metering. During our email surveys also we heard from several states who wrote simply to advise that they do not use ramp metering at all; these are not listed here.

California

An outside perspective on ramp metering California was provided by Jesse Glazer, FHWA's ITS & Operations Engineer for Southern California. Jesse addressed these topics:

- **Public acceptance.** "On-ramp metering has been ubiquitous in Los Angeles for several decades (initial sites around 1970). I recall some controversy in the first decade or so, and a study done on violation and enforcement (by Systan), but there has been no widespread controversy for 20 years or more. However, there sometimes are local controversies when a ramp queue consistently overflows and congests the surface street. But Caltrans usually installs loops at the mouth of the ramp to detect and remedy this condition. Almost all ramps in Los Angeles County are metered, and people seem to view them as fixtures."
- **Activation and operation.** "Based on personal experience, I cannot recall seeing an active ramp signal very late in the evening (i.e., past 9 p.m. or so)—they are normally dark. However, that might be a light-traffic action, and the signal is able to turn on if traffic warrants (e.g., after a late-night stadium event, or an early-morning incident). I believe that most, or all, of the ramp meters in District 7 are connected to the TMC, with some degree of control (on/off at minimum, and probably timing-plan selection). The District 7 TMC operates 24/7/365. During light traffic in the daytime, I see most signals rest in green."
- **Advance warning.** "Generally, ramp signals with limited sight distance have advanced warnings (either active or static). This situation is most common on the freeway-to-freeway connectors, some of which are metered in District 7."

As additional references, Caltrans' own ramp metering resources are cited here:

Ramp Meter Development Plan, Caltrans, 2011.

http://www.dot.ca.gov/hq/traffops/systemops/ramp_meter/RMDP.pdf

This publication “identifies all ramp meter locations that are either currently in operation or are planned for operation within the next ten year. The document is intended a tool for the Department in working with internal functional units and external partners to plan and program future ramp metering projects.”

Ramp Meter Design Manual, Caltrans, 2000.

http://www.dot.ca.gov/hq/traffops/systemops/ramp_meter/RMDM.pdf

This manual is a comprehensive resource addressing ramp meter design and operation.

Agencies with 24-Hour Ramp Metering

We learned about and corresponded with five DOTs that reported using 24-hour ramp metering: Illinois DOT, Kansas City Scout (co-managed by Missouri and Kansas DOTs), Minnesota DOT, Texas DOT, and Washington State DOT. As appropriate, we listed ramp metering resources or related research citations funded by these DOTs.

Illinois DOT

Jeff Galas with Traffic Operation noted in an email that Illinois has used ramp metering enabled on a 24-hour basis, though it is not currently active. He addressed these topics:

- **Activation and operation.** “Illinois DOT has the capability to run local traffic response, and ran a segment of I-290 for a while. The metering would activate on weekends in a congested stretch, and would shut down when free flow returned.”
- **Public reaction.** “There was no negative public reaction to this metering, since drivers would have been sitting on the ramp anyway.”
- **Current status.** “The traffic responsive system is currently shut down due to database related issues. Metering is running weekdays only based on time of day.”

Kansas City Scout (co-managed by Missouri and Kansas DOTs)

Jason Sims, Traffic Center Manager, wrote that “Kansas City Scout (Kansas City Metro), KDOT and MoDOT do, in a sense, 24/7 ramp metering.” He addressed these topics:

- **Activation and operation.** “It’s adaptive ramp metering that triggers only when mainline conditions warrant. Traditionally it activates in the peak hours and during major incidents.”
- **Public reaction.** “Scout’s initial public outreach campaign on ramp metering pushed the adaptive approach and built the expectation of Scout’s customers that it would be utilized whenever ramp metering is warranted.”

Minnesota DOT

Brian Kary, Minnesota’s Freeway Operations Engineer, discussed *de facto* 24-hour ramp metering in the state:

- **Activation and operation.** “Minnesota has a policy that limits metering to just peak hours; 5:30 AM to 9:00 AM and 2:00 PM to 7:00 PM. The policy also states that we can operate meters outside of these hours for incident related congestion. So in effect, we have 24/7 metering since the normal hours cover all recurring congestion and we have the flexibility to turn them on outside those hours for non-recurring.

“That said, it’s pretty rare that we turn meters on outside of the normal hours for incident related congestion. The meters would have to be manually activated during these situations and we would probably only get limited benefits of the meters under these conditions.”

- **Work zones.** “Most work zones we lose ramp metering because we lose detection and communication for the meter. We’ve had a couple projects where the roadway was reduced from two lanes to one where we did metering. It was only marginally effective since the mainline capacity was so greatly reduced.”

Minnesota DOT also sponsored the following 2001 research project evaluating ramp metering:

Twin Cities Ramp Meter Evaluation, 2001

<http://www.dot.state.mn.us/rampmeter/>

In this study, an independent researcher evaluated “the traffic flow and safety impacts associated with turning off all 430 ramp meters in the Minneapolis–St. Paul metro area for six weeks as mandated by the 2000 Minnesota legislature.”

Page K-7 of Appendix K—Technical Memorandum: Secondary Research

(<http://www.dot.state.mn.us/rampmeter/pdf/appendices/k.pdf>) discusses the topic of hours of operation:

“In general, most ramp meters across the country operate during the a.m. and p.m. peak periods, which range between 6:30 a.m. to 9:30 a.m. for the a.m. peak, and 2:30 p.m. to 6:30 p.m. for the p.m. peak. Ramp meters with controllers other than fixed-time may turn on or off depending on the traffic volumes or occurrence of accidents/incidents. However, most agencies use standard hours to turn on/off their ramp meters, except in emergencies, for reasons of stability and reliability in the public eye. In San Diego (CA), for example, no manual intervention or ramp overrides are ever allowed.

“However, several anomalies exist. In a busy, freeway-dependent city like Los Angeles, 32 ramp meters are operating at all times. As a result of a compromise between the Washington State Department of Transportation (WSDOT) and local neighborhood groups, a ramp meter in Seattle (WA) is only turned on during the p.m. peak (because fewer local commuters use the ramp during the afternoon hours). Due to equity issues, Detroit ramps that are close to the city centers are only metered in the off-peak direction. Another ramp meter in Seattle operates on weekends as well as weekdays.

The information above appears to be out of date. For example, Tony Kratofil at Michigan DOT wrote: “Michigan does not have any traffic-responsive ramp metering in place. We had ramp metering in the Detroit area many years ago, but it has not been active for well over 20 years and pre-existed and real time traffic-responsive technology.”

Table K.2 “Comparison of Twin Cities Evaluation Findings to Other Ramp Meter Evaluation Studies” (pages K11-K14) also lists several implementations of ramp metering, all from 2000 or earlier. These are outdated and likely of limited value for Caltrans’ current purposes. For this Preliminary Investigation, we corresponded with most of the agencies listed on this table.

Texas DOT

Texas DOT's Charlie Farnham forwarded the response from David Fink of Texas DOT's Houston TranStar office.

- **Scope of implementation.** "Currently, Houston has 80 percent of its ramp meters operating 24/7. Texas DOT is working on converting 100 percent of the meters to traffic responsive and should have that completed by the end of the summer."
- **Public reaction.** "We have had no negative complaints. In fact complaints have gone down because the meters do not come on when the traffic is light and not warranted."

Texas DOT also sponsored the following research project on ramp meter design and operation:

Development of Criteria and Guidelines for Installing, Operating, and Removing TxDOT Ramp Control Signals, Texas Transportation Institute, 2009

<http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5294-1.pdf>

Per the abstract, "The purpose of this project was to develop guidelines and criteria to assist TxDOT decision makers in determining when and where to install new ramp control signals and remove existing ramp control signals when they no longer provide a benefit to freeway traffic."

Although the report does not address 24-hour ramp metering, the detailed methods for developing guidelines and criteria for ramp metering may be of interest to Caltrans.

Virginia DOT

Markos Papageorgiou of the Technical University of Crete (see full citation and details in the "International Deployment" section of this Preliminary Investigation) wrote that Virginia DOT is implementing the Heuristic Ramp-Metering Coordination (HERO) system. It is not clear whether this is a 24-hour ramp metering operation.

Washington State DOT

Vinh Dang, Northwest Region Freeway Operations Engineer for Washington State DOT, reported on ramp metering in Washington:

- **Activation and operation.** "Ramp meters at Washington State DOT are turned on automatically on-demand with some exception. The exception is set per specific meter to handle local abnormality, such as on-ramps adjacent to sport stadium where there is tremendous need to flush traffic off the surface street network. We have tagged these ramps as 'not to be turned on (automatically) between 9:00 p.m. and 5:00 a.m.'"
- **System software, parameters and adjustments.** "Our software, written in house, was designed with the 24/7 operation in mind. The software continues to calculate and log metering rate every 20 seconds even when the meter is not "on." TMC staffs analyze and align the suggested "would be" meter rate with the traffic condition at the time. The idea is to tune the automatic on/off parameters so that the meter would not be turned on at really odd time such as late night during the most unexpected hours and low volumes. Other adjustments or tunings pertain to setting the maximum and minimum occupancy thresholds and so that the system would not oscillate on and off in a short time.
- **Signaling.** "Regarding MUTCD, I do not think they dictate the 'window of operation', but rather the display layout, the termination of 'phase'. However, I still believe the MUTCD went overboard suggesting the meter signal be the same as intersection signal in all aspects. They serve different purposes, hence have different operational needs, hence have different requirement. [This is a] pure and simple system engineering approach."

The following web page provides further resources on ramp metering in Washington State.

Ramp Meters—Studies & Publications

<http://www.wsdot.wa.gov/Traffic/Congestion/rampmeters/Studies.htm>

Other Agencies with Ramp Metering

The agencies discussed below do not operate ramp metering on a 24-hour basis. However, they offered comments on extended hours and feasibility or challenges related to 24-hour ramp metering.

Arizona DOT

Reza Karimvand, Arizona's assistant state engineer, described current and prospective ramp metering strategies in Arizona:

- **Metering times and operational modes.** “Currently, Arizona DOT’s ramp metering system runs on a set time schedule and operates during the peak periods. We use traffic responsive techniques to monitor and automatically adjust metering rates based on speeds and volumes. The time schedule was developed for each individual meter, based on corridor needs and existing traffic volumes and speeds during the peak periods. The times of day are set based on speeds less than 50 mph and where there are high entrance ramp volumes merging onto the freeway (threshold for volume is the sum of the entrance ramp and the rightmost lane, 2050 vehicles per hour or higher).”
- **Feasibility of traffic-adaptive metering; 24-hour ramp metering.** “As we move forward toward an adaptive system, I foresee Arizona DOT’s ramp metering system operating based on real time volume and speed data. Information on bottlenecks downstream will also be processed and if the thresholds are met, the ramp meters will automatically turn on and meter until congestion dissipates regardless of the time of day.”

Colorado DOT

Regional Traffic Engineer Clark Roberts described extended-hour ramp metering by Colorado DOT:

- **Implementation and metering times.** “We are using a Traffic Responsive Ramp Metering on all four eastbound ramp meters on the I-70 West Mountain Corridor. The system is currently running daily between the hours of 8:00 a.m. and 11:00 p.m., not a full 24 hours a day.”
- **Challenges—hardware functionality and construction issues.** “Overall, I like the system and how it works in corridor. That being said, we have had some significant challenges lately that are causing problems with the ramp metering system. A few weeks ago we were having com issues between the meter cabinets and the ramp metering server located in the CTMC. We have it straightened out now, but it was causing the ramp meters to run continuously during the programmed window of operation (even when I-70 volumes were low).
“The eastbound ramp meter that is located at the eastern most interchange of Idaho Springs, is being affected directly by the back ups/queues that are created by the Twin Tunnel Construction project located just to the east of the interchange. Prior to and after the com issues, the system has performed properly, and we have been watching it regularly to make sure it is only running when traffic warrants it. The construction work zone continues to be a problem as queues build and are then released, but I am not convinced that this is entirely a bad thing with the close proximity of the work zone and slow speed detour.”
- **Feasibility of 24-hour ramp metering.** “I do believe the system that we are using would allow for a full 24-hour window of operation (as traffic warrants are met), but we are not currently using it that way.”

Georgia DOT

Mark Demidovich, Georgia's assistant state traffic engineer, discussed ramp metering in Georgia. He also listed three possible drawbacks to 24-hour ramp metering.

- **Implementation.** "Here in Georgia, we operate a fairly substantial metering program of about 170 meters in metro Atlanta."
- **Metering times and operational modes.** "We are not yet running the meters in full 24-hour traffic responsive mode. Instead, we create relatively wide windows of operational hours that encompass the main peak hours. For example, on an afternoon-peak corridor, we have the meters in traffic responsive mode from 2:30 to 8 pm, meaning they can turn on anytime within those hours if freeway conditions warrant. However, the "normal" congested period is really more like 4-6:30 p.m. The widened hours encompass the "outlier" days.

"I've also set most of our core downtown meters to operate in traffic responsive mode from about noon to 7 pm on Saturday and Sunday. This strays from our normal weekday-only operation that is sufficient for all of our other locations. We did this because congestion is relatively common on the weekends in that area."

- **Feasibility of 24-hour ramp metering.** "In summary, no, [we are not operating] 24 hours yet, but have definitely considered it. My reasons against doing it have been: 1. Drivers don't expect the meters to be on at 2:00 am for example. 2. Most of the congestion we might experience in those odd-ball hours would probably be related to an incident, in which case metering has limited benefit in my opinion. 3. Detection system failures could lead to meters running in strange hours and would cause the public to question their operation."

Nevada – Regional Transportation Commission of Southern Nevada

Freeway & Arterial System of Transportation (FAST)

<http://www.nvfast.org/faq2.html#9>

It had been suggested that ramp meters in Las Vegas might be functional on a 24-hour basis. This was addressed on the FAST frequently asked questions web page. It suggests that ramp meters will be traffic-responsive in the future, but now operate on a fixed schedule or may be manually activated given appropriate circumstances.

Q 21: Why are some ramp meters operating while others are turned off? Are there different metering hours?

A 21: The purpose of ramp meters is to help regulate freeway traffic flow and merging during periods of intense use. Ramp meters in Las Vegas in the future will be "demand responsive" - that is, the meters will turn on and the metering cycles will be based on traffic flow. What this means is that meters will typically operate during periods of heavy traffic, such as weekday morning and afternoon commute hours. Now, ramp meters operate on a fixed schedule, during the morning and evening rush hours. Ramp meters also may be activated during the "off" hours in the event of an incident on the freeway or for special event traffic.

New York State DOT

John Bassett, director of New York State DOT's System Optimization Bureau, addressed ramp metering in New York:

- **Implementation and metering hours.** "In New York State we only have ramp meters on Long Island. We do not run them in 24/7 operation."
- **Feasibility of 24-hour ramp metering.** "Our Traffic Engineer on Long Island didn't think there should be any problem running them overnight as long as they are operated in actuated mode."

That way, the meters are dark except when traffic on the mainline reaches a high enough threshold to warrant the meters becoming activated.”

North Carolina DOT

Tony Wyatt with North Carolina DOT’s Transportation Mobility & Safety Division noted that the state is “working toward some of its first ramp meter locations.”

Wyatt provided a March 2013 feasibility study for ramp meters in Wake and Durham Counties (<http://www.campo-nc.us/m-0446-ramping-metering/Task-4-Screening-and-Detailed-Analysis-Final-Draft-complete-v2.1.pdf>). The study does not address 24-hour metering.

Wisconsin DOT

Anne Reshadi, Wisconsin DOT’s System Operations and Electrical Engineering Section Chief, addressed these items related to ramp metering in Wisconsin:

- **Implementation and metering times.** “Currently the majority of our ramp meters operate traffic responsive, but not on a 24 hour basis. We have 122 ramp meters operating in the Milwaukee area on the freeway system (I-94, I-894, USH 45, I-43 and I-794), of which 80 operate traffic responsive by time of day, 33 operate fixed plan and the remaining 9 currently do not meter. In the Madison area there are 5 ramp meters on USH 12/14/18 that all operate a fixed plan.”
- **Research and Evaluation.** “I have attached the only study that we have done that I am aware of, it is limited in scope and ten years old. [Note: this paper is titled “Methods for Evaluating Ramp Meters in Milwaukee: Case Studies of Microscopic and Macroscopic Models” and is 57 pages. CTC provided this separately to Caltrans.]

“As part of a larger contract effort we are planning on completing a system wide evaluation of our ramp metering operations this year. Operating the ramp meters traffic responsive in the Milwaukee area has been highly effective in maintaining flow on the freeway network. Once in a while we receive complaints from the public as to why they have to wait at a ramp meter while the freeway is flowing well.”

International Resources and Deployment

In this section, we cited two documents that provide international guidance on ramp metering: detailed operational guidance from an Australian state and a document aimed at harmonizing ramp metering throughout Europe. This is followed by our correspondence with international practitioners and experts on this topic.

Guidance Documents

Victoria, Australia—Freeway Ramp Signals Handbook, VicRoads, 2010

<http://www.vicroads.vic.gov.au/Home/Moreinfoandservices/RoadManagementAndDesign/DesignStandardsManualsNotes/ManagedFreewayManuals/FreewayRampSignalsHandbook.htm>

“The Freeway Ramp Signals Handbook” is VicRoads’ primary reference for planning, designing and operating freeway entry ramp signals.

Section 7.3—Times of Operation in Chapter 7—Operation of Ramp Signals

(<http://www.vicroads.vic.gov.au/NR/rdonlyres/2871C246-1217-4A2E-AC11-C022E8D03C38/0/Ch7.pdf>)

describes four operation modes:

- Dynamic Activation and Deactivation.
- Time of Day Activation.
- During Incidents and Events.
- Manual Operation.

Paragraph 7.3.1—Dynamic Activation and Deactivation includes the following discussion relevant to this Preliminary Investigation:

The dynamic switch-on and switch-off of ramp signals is based on the prevailing freeway traffic conditions. A dynamic system provides traffic responsive operation that activates the metering signals at any time when warranted by freeway traffic flow conditions that could lead to the onset of flow breakdown. The activation and deactivation thresholds are set for each ramp/bottleneck during the manual fine tuning of the system.

The switch-on criteria are based on a combination of speed, occupancy and/or volume. Different criteria are used for starting up and switching off the signals. The switching on criteria are usually set at a relatively low threshold to be sure that the signals start up before the freeway flow collapses. The criteria need to be comprehensive to avoid the signals switching on at an inappropriate time, e.g., high occupancy and low speeds may occur at night due to a slow moving maintenance vehicle.

Usually, stronger criteria are used for switching off the signals to ensure the signals will not start up again soon after the deactivation.

Europe—Ramp Metering Deployment Guideline, EasyWay (a “trans-European project co-financed by the European Commission”), 2012.

http://www2.liikennevirasto.fi/ew/ew-tms-dg03_rampmetering_01-02-00.pdf

This publication is part of an effort to harmonize ramp metering throughout Europe. Its scope addresses “end-user aspects (drivers and operators), ensuring drivers across Europe encounter similar conditions (including “look and feeling”) when driving in ramp metered areas. This includes:

- “Pre-signing on the on-ramp.
- “Yellow backing shield to ramp metering signal heads.
- “Use of GREEN-AMBER-RED signal cycle.

“Due to heterogeneity of existing deployments and traffic management procedures, technical aspects, such as specific algorithms and detecting methods are not required to be harmonized.” The guide also presents case studies on a number of implementations in different European cities.

Two individuals we contacted discussed this guide:

- Henk Jan de Haan of the Netherlands' National Traffic Management Centre wrote: "In Europe, all Road Authorities of the European Road Network are working very closely together to get things harmonized all over Europe. We are sponsored by the European Commission for this cooperation that is named 'EasyWay.' "
- David Laoide-Kemp of Ireland's National Roads Authority wrote: "The UK and other European countries do use ramp metering however. I don't have any direct contact in those authorities, but can direct you towards the EasyWay Deployment Guidelines which refers to many examples of best practice."

Deployment

We corresponded with an expert from Greece, who reported on the status of traffic-responsive ramp metering in Australia and France. We also corresponded with practitioners from three European nations that use ramp metering—Germany, the Netherlands and Sweden. We did not receive firm confirmation of 24-hour ramp metering in any other foreign country than the Netherlands, though it was suggested that the HERO system used in Australia and France was also operated on a 24-hour basis.

Australia; France

Markos Papageorgiou with the Technical University of Crete wrote that "The most prominent example of highly successful ramp metering system employing our HERO (Heuristic Ramp-Metering Coordination) strategy is the one on freeway M1 in Melbourne, Australia with 65 metered ramps." The deployment is detailed in the following citation.

"Heuristic Ramp-Metering Coordination Strategy Implemented at Monash Freeway, Australia," Ioannis Papamichail, Markos Papageorgiou, Vincent Vong, and John Gaffney, *Transportation Research Record* of the Transportation Research Board, Volume 2178, 2010: 10-20. <http://trid.trb.org/view/2010/C/909624>.

This paper presents "a new traffic-responsive feedback control strategy, heuristic ramp-metering coordination (HERO) that coordinates local ramp-metering actions in freeway networks. The proposed coordination scheme is simple and reactive [i.e., based on readily available real-time measurements without the need for real-time model calculations or external disturbance (e.g., demand) prediction]. HERO employs an extended version of the feedback regulator ALINEA at the local level. ... This pilot project is part of the Monash–CityLink–West Gate (MCW) upgrade [in Melbourne, Australia]. The obtained results showed a significant increase of traffic throughput and a reduction of travel times compared with the previously used ramp-metering system. To maximize performance across the entire 75-km route of the MCW upgrade, HERO was under implementation at 63 on-ramps."

Papageorgiou notes further that HERO is also operational in Brisbane, Australia and is in implementation phase at M80, Victoria, Australia and in Grenoble, France. It is not clear whether these are 24-hour ramp metering operations, and we were unable to get clarification on this point.

Germany

Josef Kaltwasser with Albrecht Consult wrote: "Ramp Metering is widely used in Germany, as in some other places in Europe. I can try to dig for experience reports over here, but I fear they would certainly be in German language."

Netherlands

We corresponded with two individuals who work with the Netherlands' National Traffic Management Center.

Henk Taale is with the Netherlands' TrafficQuest Centre for Expertise on Traffic Management, a joint effort of the National Traffic Management Center and Delft University of Technology. Taale addressed the following items regarding ramp meters in the Netherlands:

- **Deployment.** "As of January 1, 2013 about 115 ramp metering systems are operational in the Netherlands. The first ramp metering was installed in 1989 near Amsterdam. Since then and based on evaluation studies, ramp metering systems have been implemented on a lot of on-ramps in our country."
- **Activation and operation.** "They work 24 hours and are traffic responsive. Typically they are only active during one or two peak periods during working days."
- **References.** "English publications on ramp metering in The Netherlands are attached." [Links, where available, are provided below. CTC provided these citations in full PDF format separately to Caltrans.]
 - "Ramp Metering in The Netherlands: An Overview," F. Middelham and H. Taale, Preprints of the 11th IFAC Symposium on Control in Transportation Systems, Delft, The Netherlands, August 29-31, 2006, pp. 267-272.
<http://www.ifac-papersonline.net/Detailed/30997.html>
 - "Ten Years of Ramp-Metering in The Netherlands," H. Taale and F. Middelham, Proceedings of the 10th International Conference on Road Transport Information and Control, IEE, London, April 2000, ISBN 0-85296-725-X, pp. 106-110.
<http://ieeexplore.ieee.org/xpl/login.jsp?reload=true&tp=&arnumber=861243>
 - "The Assessment of Ramp Metering Based on Fuzzy Logic," H. Taale, J. Rosloot and J. Slager, Proceedings of the 3rd World Congress on Intelligent Transport Systems, ERTICO, Orlando, October 1996.
 - "The Assessment of Multiple Ramp-Metering on the Ringroad of Amsterdam," H. Taale and G. A. van Velzen, Proceedings of the 8th International Conference on Road Traffic Monitoring and Control, IEE, London, April 1996.

Henk Jan de Haan of the Netherlands' National Traffic Management Centre provided a different answer: "In the Netherlands we use ramp metering systems on a wide scale. In my opinion never on a 24 hour basis. They are quite effective, as can be read from evaluation reports. Most of the time they are in Dutch." It was unclear whether Jan de Haan meant that ramp meters are not *available* on a 24-hour basis or are not *actively metering* on a 24-hour basis. Based on Taale's detailed answer above, the conclusion that the Netherlands uses 24-hour traffic-responsive ramp metering appears to be sound, though further inquiries might be appropriate.

Sweden

Bjarne Holmgren, traffic management operations manager for the Swedish Transportation Administration, wrote "I did find an evaluation report about ramp metering in Stockholm from 2006, but unfortunately it's only available in Swedish. I will try to find someone else who knows if the systems are operating 24/7. Even if they are turned on, they will not operate unless the situation requires it and I expect that this will occur in morning and afternoon rush hours." CTC received this report in Swedish from Holmgren and can send it if Caltrans is interested in it.